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2020 Report of the
NWMO Adaptive Phased Management
Geoscientific Review Group (GRG)

- Preliminary Geoscientific Assessments -

December 2020



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2020 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG) December 2020

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Geoscientific Review Group Report 2020

Executive summary

This report summarizes the work completed in 2020 by the Adaptive Phased Management Geoscientific Review Group (APM-GRG; abbreviated to GRG). This year, due to the Covid-19 pandemic, all GRG meetings were held in a virtual format. The GRG and NWMO met once by teleconference call and six times by web-meeting. From September 2020 onward, the two-hour meetings have been held at least monthly.

The GRG reviews approaches, methods, criteria and findings related to broad geoscientific issues addressed by the NWMO. Focus during 2020 was on activities in crystalline rock in the northern part of the Revell Batholith, Ignace area, and on test plans for drilling of the first borehole (SB_BH01) in Paleozoic sedimentary rock in the South Bruce area.

For the Ignace area, the GRG reviewed technical reports addressing the first stage of geoscientific data analysis, data integration and modelling at this crystalline rock site. These included: (1) two rounds of review of the Phase 2 initial borehole drilling and testing, WP10 geological integration report for borehole IG_BH01; (2) a review of a similar WP10 report for borehole IG_BH03; (3) a 3D geophysical model for the Revell Batholith and surrounding greenstone belts; (4) a new synthesis of the bedrock geology at the ground surface inside the regional area centered on the Revell Batholith and including surrounding greenstone belts; and (5) a 3D seismic velocity model for the Revell Batholith. Reviews for the Ignace area also involved an assessment of test plans for the installation of micro-seismic monitoring stations in the Revell Batholith, for the acquisition of 2D seismic data in an area surrounding the borehole locations, and for conducting Vertical Seismic Profiling (VSP) in borehole IG_BH04.

For the South Bruce area, the GRG has started to review test plans in connection with the drilling of borehole SB_BH01 at the site, and has commented on challenges related to consistency with the work and reporting being carried out in the Ignace area. The test plans included activities labelled WP03 (Geological and Geotechnical Core Logging, Photography and Sampling), WP04C (Porewater Extraction and Analysis and Petrographic Analysis), WP04D (Mineralogical and Geochemical Analysis of Core), WP04G (Organic Geochemistry and Whole Rock and Clay Mineralogy) and WP06 (Hydraulic Testing). Further test plans are expected to be submitted shortly to the GRG for review and these plans will be covered in the GRG 2021 annual report.

A member of the GRG also completed feedback to the NWMO outside of the normal GRG site characterization review procedure bearing on Canadian Shield hydrogeological and hydrogeochemical data compilations, and sorption measurements on core samples.

As in previous years, the GRG made various contributions to geoscientific aspects and these are briefly described in this report. The NWMO documented all suggestions, questions and comments by the GRG in disposition tables, and described how they intend to address them. The NWMO continues to provide high-quality responses to all points raised by the GRG in a timely, transparent and professional manner. The GRG wishes to point out that feedback through the detailed disposition tables are most helpful for the GRG to monitor the impact of the review effort. NWMO is to be congratulated for their outstanding efforts with these tables. In the members' opinion, the adopted approach continues to follow or exceed international practices in this phase of assessment.

The GRG's overall assessment of the progress during 2020 is very positive despite the complications imposed by the Covid-19 pandemic. The systematic, iterative approach executed by the NWMO for the crystalline rock site at Ignace is now being planned and applied to the sedimentary rock site at South Bruce. The GRG is satisfied that considerable input during 2020 in the Ignace area has been on data analysis and modelling on a regional scale covering the northern part of the Revell Batholith and surrounding greenstone belts, including development of a regional groundwater model. Increasing attention is now being placed on modelling on a local scale within a volume comprising a 25 km² area surrounding the boreholes and extending to 1.5 km depth (Revell site). In this context, the GRG feels

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that good progress has been made in the analysis and integration of data from boreholes IG_BH01 to IG_BH03, in preparation for the forthcoming first versions of the 3D geological model (3DGM), the Discrete Fracture Network model (DFN) and the Descriptive Geoscientific Site Model (DGSM) for the Revell site. The work undertaken by the NWMO team and its consultants is presented in high-quality documents. The timely planning by the NWMO geoscientific team to support our review work allowed the GRG to fulfil its mandate.

Technical and scientific aspects are described in the main body of this report. A few high-level aspects are highlighted here:

- The GRG is pleased to see that NWMO has implemented the various organizational and model planning recommendations proposed in the GRG annual report for 2019 to meet the challenging timeline.
- The GRG notes that new resourcing has enabled the NWMO to execute some of the reporting tasks previously assigned to consultants, which has resulted in an improvement in the quality and consistency of documents.
- The GRG recommends that NWMO define the criteria for adoption of the term 'zone' in the context of different structural features along a borehole and describe in detail the character of each zone in the WP10 (geological integration) documents.
- Lineaments at the ground surface are potentially of vital importance in the context of repository safety. For this reason, it is necessary to understand better their geological character and to complete such a study (or studies) before a single site is selected for detailed site investigation. Focused drilling, as envisaged for forthcoming boreholes IG_BH05 and IG_BH06, and fracture mapping along excavated trenches are recommended.
- The GRG recommends converting all porosity and water content data along boreholes into volumetric values expressed as either wt % or vol %, and then to compare the data and make an attempt to interpret the differences.
- Reviews of the subregional-scale DFN and groundwater models are currently ongoing, and conclusions will be included in the GRG 2021 annual report.

The GRG is looking forward to seeing the first versions of the site-scale 3D geological and DFN models in the Ignace area (Revell site) and to how the challenges around integration of the deterministic and stochastic modelling techniques are addressed. Integration of the results from other disciplines with these models in the first version of the DGSM for the Revell site will be of fundamental importance. The GRG also awaits with interest to see the results of further drilling and seismic investigations at Ignace, and the start of drilling in the South Bruce area.

Geoscientific Review Group Report 2020

1 Introduction

The Adaptive Phased Management Geoscientific Review Group (APM-GRG; abbreviated to GRG) was established by NWMO in 2012. It aims to provide independent review comments and advice on the preliminary geoscientific assessments being conducted as part of NWMO's evaluations to identify a suitable deep geological repository site for Canada's used nuclear fuel in an informed and willing host community. More specifically, the GRG provides comments on the approach, methods and criteria used, the data interpretation, and the adequacy of proposed preliminary field investigation and drilling programs to advance the understanding of the geology and increase confidence in the potential suitability of the various siting areas being considered by NWMO.

This report covers the activities of the GRG during the year 2020. Previous GRG reports were issued in December 2013, 2014, 2016, 2017, 2018 and 2019, and are publicly available on NWMO's website (APM-GRG 2013, 2014, 2016, 2017, 2018, 2019 www.nwmo.ca). Brief biographies of the GRG members for the 2020 term are attached to this report.

2 Objectives of NWMO's geoscientific preliminary assessments

The suitability of communities is assessed using a staged approach including 'Initial Screenings', 'Preliminary Assessments' and 'Detailed Site Characterization', and considers both technical and community well-being factors (NWMO 2010).

The overall preliminary assessment is conducted through a series of technical, socio-economic and cultural studies conducted in two phases over several years. Technical studies involve geoscience, engineering, transportation, environment and safety. The objective of the geoscientific suitability preliminary assessment is to assess whether candidate areas have the potential to meet NWMO's site evaluation factors (geoscientific suitability). The two phases are:

- *Phase 1 - Desktop Study:* Undertaken for all communities electing to be the focus of a preliminary assessment. This phase involved desktop studies using available geoscientific information, and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the preliminary assessment. Desktop studies for all communities are completed.
- *Phase 2 - Preliminary Field Investigations:* Undertaken to further assess the potential suitability of a subset of communities selected by the NWMO. Depending on the geological setting, Phase 2 field investigations can include high-resolution surface and airborne surveys, geological mapping and initial borehole drilling.

The subset of communities advanced to Phase 2 preliminary assessment were selected based on the findings from the desktop study during Phase 1, considering technical, socio-economic and cultural considerations. It is important to note that the mandate of the GRG is exclusively focussed on the approach, methods, criteria and findings associated with the geoscientific suitability assessments. The GRG is not involved in matters pertaining to transportation and environment and is not consulted when narrowing down the number of communities.

The status of involvement by different communities in NWMO's site selection process as of December 2020 is illustrated in Figure 1. There are currently two communities remaining in the site selection process. They are both in Phase 2 of the preliminary assessment, and include Ignace on crystalline rock, and South Bruce on Paleozoic sedimentary rock. During 2020, the GRG reviewed geoscience reports related to the Ignace community. Review activities related to the sedimentary site (South Bruce) involved test plans for borehole SB_BH01 in that area.

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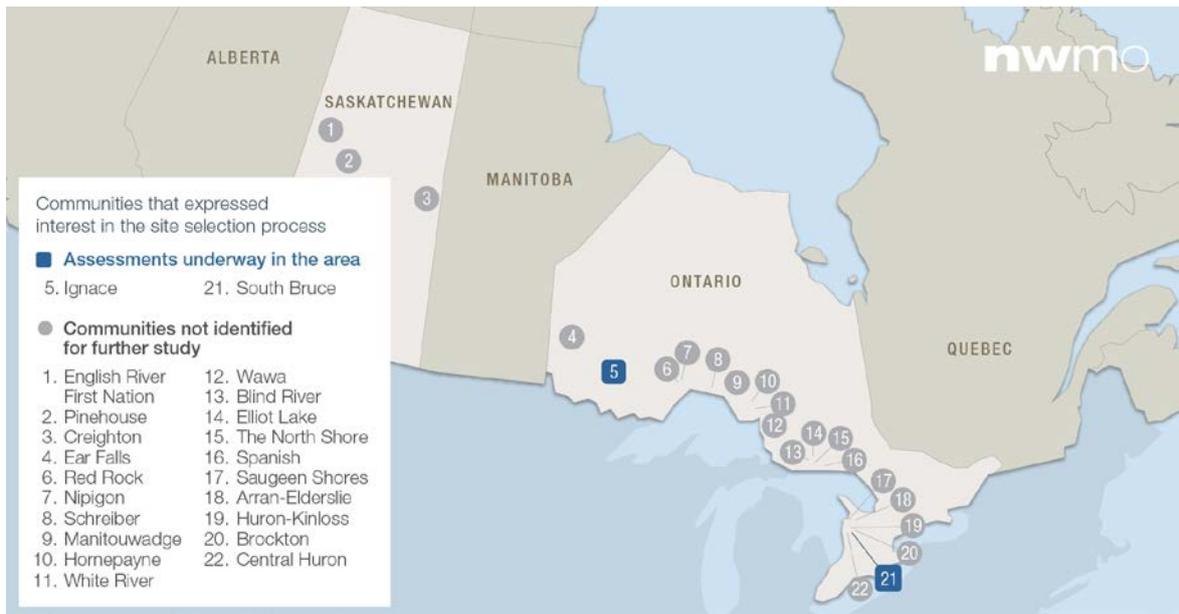


Figure 1. Communities that expressed interest in the site selection process (as of December 2020). Communities 1 to 16 are located on crystalline rock, and communities 17 to 22 on sedimentary rock.

3 GRG review activities in 2020

As the following list of activities illustrates, 2020 was another active period for the GRG. Due to the Covid-19 pandemic, virtual meetings were held with seven teleconferences/web-meetings to discuss specific technical/scientific issues, and to discuss questions and recommendations emerging from the reviews of many documents. The GRG continued to fulfill its advisory function on forthcoming work tasks.

3.1 Meetings between GRG and NWMO

In 2020, the GRG has been involved in reviewing NWMO's geoscientific activities in the communities of Wabigoon Lake Ojibway Nation and Ignace, Ontario, referred to here as the 'Ignace area'. The GRG also reviewed NWMO's geoscientific activities related to the planning of drilling in the South Bruce area, Ontario. Both communities are in Phase 2 of the preliminary assessment. The meetings included:

- Teleconference call on February 18, 2020.
Focus: WP10 geological integration report for borehole IG_BH01; planning for Descriptive Geoscientific Site Model (DGSM) at Ignace/ ongoing work/ future plans.
- Web-meeting June 22, 2020.
Focus: Ignace site-scale 3D geological model (3DGM); hydraulic test results, and preliminary hydrogeology and hydro-geochemistry site models; VSP and 2D seismic planning/ ongoing work/ future plans.
- Web-meeting September 21, 2020.
Focus: Hydro-geochemistry results/ongoing work/ future plans.
- Web-meeting October 22, 2020.
Focus: Geomechanics results/ Identification of possible fracture zones in boreholes/ ongoing work/ future plans.
- Web-meeting November 18, 2020.
Focus: Thermal and transport properties results; sedimentary rock drilling test plans at South Bruce/ ongoing work/ future plans.

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- Web-meeting November 23, 2020.
Focus: Issues arising from review activities.
- Web-meeting December 11, 2020.
Focus: Integration of geological model with other DGSM discipline data sets.

Feedback from the GRG for consideration by the NWMO was shared following each virtual meeting but, more importantly, individual GRG members communicated directly by e-mail. Overall, the GRG is highly satisfied with the adopted mode of communication that allows the GRG to operate effectively.

The GRG is pleased to see that the NWMO has implemented the high-level aspects addressing organizational and model planning aspects to meet the challenging timeline, highlighted in the GRG annual report for 2019 (APM-GRG 2019). These include creation of two subgroups within NWMO's Geoscience team, one focussing on data acquisition and the other on data interpretation and modelling; establishment of a new organization for the production of the 'Single Borehole Data Integration Report', starting with the production of a WP10 geological interpretation report and followed by production of draft documents for the integration of other disciplines (geomechanics, hydrogeology, hydro-geochemistry, and transport and thermal properties) as part of the preparation for the DGSM; development of a work-flow strategy for establishment of the 3DGM; and adoption of a plan for one iteration in the DGSM development prior to 2023 using integrated data from the ground surface and from boreholes IG_BH01 to IG_BH03. However, the GRG is still concerned that the team will struggle to deliver all required work within the adopted aggressive timeline. The work completed during 2020 has not fully reached the goals set in the timeline requested by the GRG at the February teleconference, thereby justifying GRG's concern about the timeline.

The GRG notes that the new resourcing has improved NWMO's ability to assume some of the reporting tasks previously assigned to consultants. This has greatly improved the quality and consistency of the reporting.

The GRG provided feedback concerning the identification of possible fracture zones along boreholes using statistical analysis of fracture frequency and is impressed with the approach now being used by the NWMO to identify such zones along IG_BH01 to IG_BH03. The GRG also welcomes the decision to include this analysis in the WP10 (geological integration) technical report for each borehole at Ignace. However, it is clear that there are challenges linking the fracture clusters along boreholes IG_BH01 to IG_BH03 to lineaments, most of which have the potential to represent the surface expression of fractures and fracture zones that may act as potential groundwater flow pathways, and zones of geomechanical instability or potential reactivation (DesRoches et al. 2018). The GRG recommends that NWMO defines the criteria for adoption of the term 'zone' in the context of different structural features along a borehole and describe in detail the character of each zone in the WP10 (geological integration) documents.

Bearing in mind the potential importance of lineaments for safety requirements (DesRoches et al. 2018), the GRG recommends a focused study (or studies) of lineaments in forthcoming field investigations at Ignace. This work should be completed prior to the selection of a single site for detailed investigations during 2023. The GRG recommends considering the use of one or more field techniques, including focused drilling and fracture mapping along excavated trenches. In this context, the GRG is pleased that the forthcoming boreholes IG_BH05 and IG_BH06 are planned to intersect structures potentially linking to lineaments at the ground surface.

Since there is a need to compare porosity and water content data along boreholes, the GRG also recommends converting all water-loss data into volumetric values and then to compare the data and make an attempt to interpret the complete data set.

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Figure 2. APM-GRG members at their last in-person meeting in 2019 (top; from left to right: Michael Stephens, Peter Kaiser (Chairman), Sandy Cruden, Andreas Gautschi and Anders Ström) and one year later at a virtual web-meeting in November 2020 (bottom)

3.2 Specific studies reviewed by the GRG

The GRG systematically reviewed approaches, methods and findings reported in the following geoscientific studies, and summarizes some comments on them in later sections of this report. Most of these activities specifically address the potential site in the Ignace area (Revell site). They include the first stage of geoscientific data analysis, data integration and modelling in crystalline rock in the Ignace area (Section 5.1), and test plans for acquisition of seismic data in this area (Section 5.2):

- Review of Phase 2 initial borehole drilling and testing, Ignace area: WP10 - geological integration report for borehole IG_BH01 (Section 5.1).
- Review of Phase 2 initial borehole drilling and testing, Ignace area: WP10 - geological integration report for borehole IG_BH03 (Section 5.1).
- Review of 3D geophysical forward and inversion modelling of the Revell Batholith and surrounding greenstone belt (Section 5.1).
- Review of bedrock geology of the Revell Batholith and surrounding greenstone belts (Section 5.1).
- Review of 3D seismic velocity model for the Revell Batholith (Section 5.1).
- Review of test plan for a micro-seismic monitoring project in the Ignace area (Section 5.2).
- Review of test plan for 2D seismic investigation in the Ignace area (Section 5.2).
- Review of test plan for Phase 2 initial borehole drilling and testing: WP12 - Vertical Seismic

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Profiling (VSP) along borehole IG_BH04 (Section 5.2).

The GRG also reviewed test plans for the initial borehole drilling program in Paleozoic sedimentary rock in the South Bruce area along borehole SB_BH01 (Section 5.3):

- Review of WP03 test plan: geological and geotechnical core logging, photography and sampling.
- Review of WP04C test plan: porewater extraction and analysis, and petrographic analysis.
- Review of WP04D test plan: mineralogical and geochemical analysis of core.
- Review of W004G test plan: organic geochemistry, and whole rock and clay mineralogy.
- Review of WP06 test plan: hydraulic testing.

Following communication directly by e-mail or discussion during a virtual meeting, a member of the GRG also completed feedback to the NWMO outside of the normal GRG site characterization review procedure. Three issues in this category were addressed:

- A review of a draft of a data compilation led by the NWMO Research and Development (R&D) team: 'Equivalent porous media rock mass and fracture zone permeability versus depth in a Canadian Precambrian rock setting' written by University of Waterloo geoscientists, to be published in the open literature.
- Detailed comments on a draft scope of work entitled 'State of Science Review of Groundwater and Porewater in Cratonic Crystalline Rocks' written by the NWMO R&D and Geoscience teams.
- A review of a test plan (WP04E) on sorption core testing for IG_BH04 to be carried out by the Safety Assessment Group in the context of NWMO's R&D program.

The comments were appreciated by the R&D Team and, where necessary, will be addressed in the updated versions.

4 Overall assessment of progress during 2020

The GRG's review process followed the same approach as in previous years, although all meetings were held in virtual format in 2020 due to the Covid-19 pandemic:

- Prior to meetings, NWMO shared draft work plans and initial findings in technical reports, as they became available, in order to solicit review comments,
- The web-meetings, teleconferences and e-mail exchanges with NWMO were held to discuss the GRG's review comments, and
- GRG comments to all technical reports were documented and tracked in disposition tables, which, together with NWMO responses and in several cases final dispositions (see below), were returned to the GRG to ensure that the approach to address the review comments was appropriate.

The GRG's overall contributions in 2020 focussed on the tasks listed in Section 3.2, the results of which were presented to the GRG in the form of technical documents or oral presentations at the meetings.

The GRG is still most satisfied with the systematic, iterative approach and the methods adopted by the NWMO, and is highly impressed by the progress made despite the disruptions by the Covid-19 pandemic. In particular, the GRG is pleased that efforts have been taken during 2020 to complete different tasks in the regional-scale model for the northern part of the Revell Batholith and surrounding greenstone belts, and that focus is now being focused on various aspects of the local-scale model within a volume comprising a 25 km² area surrounding the boreholes and extending to a depth of 1.5 km (Revell site). The GRG also appreciates that the NWMO has decided on the content of the geoscientific information to be modelled in DGSM (Version 1) with the aim to complete this model

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during 2021. In this context, the GRG notes considerable progress has been made with the 3D geological model (3DGM) and the Discrete Fracture Network model (DFN) at the Revell site, which form the foundation for the DGSM. All this work has been carried out in parallel with detailed planning for the acquisition of seismic data and forthcoming drilling in the Ignace area, and for the initiation of drilling at the Paleozoic sedimentary rock site in South Bruce.

The NWMO team and its consultants have again undertaken high-quality work. The approach adopted by NWMO allowed the GRG to review findings and progress in detail, and the GRG was able to provide timely input for consideration by NWMO. Suggestions by the GRG for process improvements were considered and implemented by NWMO in a rapid, transparent and professional manner. The GRG wishes to point out that NWMO has provided timely and excellent feedback through the disposition tables that are most helpful for the GRG to monitor the impact of the review effort. NWMO is to be congratulated for their outstanding efforts with these tables. As a consequence, NWMO continues to maintain a high standard of quality work and is making steady progress in the site evaluation process at Ignace and in preparation for the initiation of this work at South Bruce. In the GRG members' opinion, the adopted approach continues to follow or exceed international practices.

5 GRG review comments

5.1 Data analysis, integration and modelling at the Ignace crystalline rock site

- *Review of Phase 2 initial borehole drilling and testing, Ignace area: WP10 – geological integration report for borehole IG_BH01*

The GRG reviewed two separate versions of the WP10 integration report for borehole IG_BH01, a first version entitled 'WP10 Single Borehole Geoscientific Data Integration Report for IG_BH01' in early 2020 and a second one entitled 'Geological Integration Report for Borehole IG_BH01' in May 2020.

The first version contained data from all geoscientific disciplines (geological, petrophysical analysis, geomechanical, geophysical core logging, hydraulic testing, groundwater sampling etc.) and the GRG provided detailed comments and recommendations for revisions concerning all these disciplines. Following a GRG recommendation to establish a new organization for the production of the single borehole data integration report (APM-GRG 2019) and because the data set from BH01 is still not complete (e.g., ongoing water sampling in the Westbay multi-packer system of BH01), the GRG is pleased that the NWMO decided to revise the methodology by integrating, in a first round, information from work packages WPO2, WPO3 and WPO5 into a geological integration report. The data from other disciplines will be presented and integrated in the forthcoming DGSM report, with the chance to obtain a broader view with data from more than one borehole.

Relative to the first version, the 'Geological Integration Report for Borehole IG_BH01' reviewed in May 2020 provided a much-improved evaluation of rock composition at the Revell site with the addition of whole-rock geochemical data, a better integration of geological and geophysical core logging data so that down-hole geophysical anomalies were linked in more detail to the geological features along the borehole, and an improved identification of fracture sets. The GRG remained concerned about how it has been decided which fractures mapped as broken during the core logging actually have a natural aperture, i.e., are potentially open for groundwater flow. This information is of significance for hydrogeological modelling.

- *Review of Phase 2 initial borehole drilling and testing, Ignace area: WP10 – geological integration report for borehole IG_BH03*

The GRG members were pleased that the structure of the WP10 geological integration report for borehole IG_BH03 is identical to that used in the equivalent report for IG_BH01 (see above). The only difference is the addition of text addressing the identification of fracture zones along the borehole, which is a welcome development and will be applied to all forthcoming WP10 reports as

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well as a modified version of the WP10 report for borehole IG_BH01. The review work has invoked a discussion around the nomenclature being used for such zones and a request for a tighter definition of zones with different structural characteristics along boreholes. The question around the attribute 'aperture' of fractures raised in the review of the WP10 report for borehole IG_BH01 remains. The GRG also requested more information around the mineralogy associated with hydrothermal potassic alteration and how this alteration is distinguished optically from hematite alteration during the core logging procedure. The NWMO has replied that they are actively trying to characterize better the nature of these two types of alteration.

- *Review of 3D geophysical forward and inversion modelling of the Revell Batholith and surrounding greenstone belt*

This report is well-structured and provides a regional model for the 3D distribution of major rock units in the volume occupied by the Revell Batholith and the surrounding greenstone belt. This model will form a significant component for the 3DGM. All changes submitted by GRG members to improve the quality and clarity of presentation in the technical report have either been implemented or reviewed by the NWMO and modified appropriately. One example involves the need for consistency in the usage of lithological terms in the text and figures.

- *Review of bedrock geology of the Revell Batholith and surrounding greenstone belts*

The GRG were very impressed with the overall quality of this report and the progress made by the NWMO team in characterising the bedrock geology of the Revell Batholith region. The GRG suggested that more clarity on the 3D structure of the batholith would be provided by the inclusion of a vertical cross-section. This recommendation and a number of additional technical clarifications and improvements to the quality of the writing suggested by the GRG have been implemented in the final version of the report.

- *Review of 3D seismic velocity model for the Revell Batholith*

The GRG was satisfied that the 3D seismic velocity modelling procedure for the Revell Batholith made use of established methods for such modelling work. Several recommendations were made for improving the text. In particular, the need to document a motivation for the modelling work in the context of other activities at the Ignace crystalline rock site was identified. The GRG also requested the authors clarify all reference to model volumes throughout the text.

5.2 Test plans for acquisition of seismic data at the Ignace crystalline rock site

- *Review of micro-seismic monitoring project in the Ignace area*

The GRG provided several comments to help improve the standard of presentation of the test plan for micro-seismic monitoring. NWMO has informed the GRG that the changes have been implemented. The GRG identified a need to place this study in a broader context and to provide a review of previous measurements from national seismic networks. The NWMO have replied that these issues will be addressed in the annual reports to be completed in connection with the execution of the monitoring program.

- *Review of 2D seismic investigation in the Ignace area*

The GRG expressed concern that the test plan did not clearly address the need to integrate the results of the 2D seismic investigation with the structural and geophysical logs acquired during drilling. Unfortunately, the seismic lines were not shown on a geological map of the Ignace site showing lineaments inferred to represent brittle deformation zones and borehole locations. Both of these issues have been modified in the revised test plan presented to the GRG. The GRG also expressed concern around the location of the seismic lines with respect to the location of the boreholes and their partly crooked character. The NWMO responded by emphasizing the logistical problems at the site and the adjustments that have been made to minimize crookedness along the seismic lines.

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- *Review of Phase 2 initial borehole drilling and testing: WP12 – Vertical Seismic Profiling (VSP) along borehole IG_BH04*

The GRG made several suggestions to improve the standard of presentation of the test plan for the acquisition of VSP data along borehole IG_BH04 and have been informed by NWMO that virtually all these changes have been implemented. As for the 2D seismic investigation in the Ignace area, the test plan did not clearly address the need to integrate the VSP reflectors with the structural and geophysical logs acquired during drilling. Furthermore, the GRG considered that the test plan placed too much emphasis on the ability of VSP reflectors to be linked simply to fracture zones, avoiding the possible input from, for example, contacts between lithological units, e.g. amphibolite and granitoid. Uncertainties around exactly to which geological feature a reflector is related need to be discussed. The GRG also advised NWMO to instruct the consultants to report orientation measurements of planar structures in the standard manner used at NWMO.

5.3 Plans for Phase 2 initial borehole drilling and testing at the South Bruce sedimentary rock site – Borehole SB_BH01

- *Review of WP03 test plan: geological and geotechnical core logging, photography and sampling*

This test plan (including the manual in Appendix 1) is very well-structured and has been judged to successfully transfer virtually all the necessary information to the geologists doing the core logging. Nevertheless, the GRG has provided several modifications that will help to improve and clarify its content. Two examples concern usage of the term 'natural fractures' and the need for some serious re-thinking around the definition and measurement of the attribute 'aperture' along fractures. The GRG also pointed out the need for some care in the treatment of partially intact fractures. If the assumption made in the test plan that the broken portions of these fractures are the result of a mechanical process is wrong, and partially intact structures are grouped incorrectly with intact structures, this exercise could have serious consequences for both geomechanics and hydrogeology. The GRG recommended that NWMO should test this assumption during analysis of the WP05 televiewer data and to address the issue in the WP10 report for borehole SB_BH01.

- *Review of WP04C test plan: porewater extraction and analysis and petrographic analysis*

This test plan is a follow up of the work that the University of Ottawa has carried out for the OPG Bruce Site project about 12 years ago, but includes a new method (porewater characterisation by paper absorption) which is still in development. The GRG recommended the NWMO to evaluate and test also other newly developed porewater characterization methods (porewater squeezing, diffusive exchange of stable isotopes of water) that have been tested successfully during the last few years in the context of a benchmarking exercise published in the NWMO Technical Report series.

- *Review of WP04D test plan: mineralogical and geochemical analysis of core*

The WP04D report is well-structured and well-written with descriptions of all planned analytical methods. It mirrors the broad and in-depth experience of the team involved. The GRG requested more information around certain aspects in the test plan, for example the need to address the strategy concerning choice of core section for sampling and subsequent analytical work. Furthermore, the GRG expressed the need to carry out a mineralogical study on all samples chosen for whole-rock geochemical analysis. The GRG also noted that some issues were not included in the test plan, for example a study of the pore microstructure at thin-section scale and age dating of fracture infill. The GRG considered that it would be helpful for the reader to know whether such issues are to be addressed in other studies of borehole SB_BH01.

- *Review of WP04G test plan: organic geochemistry, and whole rock and clay mineralogy*

The GRG was not satisfied that the experiences from the investigations at the Bruce nuclear site about 10 years ago were not taken into account in the test plan and recommends a corresponding revision. The highest contents of organic carbon at Bruce are represented by a distinct peak in the Collingwood

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Member of the Cobourg Formation. Fortunately, it could be shown that the thickness of this layer is too limited to represent a potential shale gas reservoir. The sampling program for organic carbon analyses in the planned South Bruce borehole (see WP03) only includes one sample per formation. The GRG recommends increasing the sampling rate in the section of the Collingwood Member and the surrounding rock formations.

- *Review of WP06 test plan: hydraulic testing*

This test plan is very mature and well-formulated. The broad experience of the team is obvious. All important aspects of hydraulic testing in a very low permeability environment (Packer pressure monitoring and maintenance, test-zone compressibility, skin effects) have been addressed and will be handled appropriately in the testing program. The GRG only noted missing information on the chemical composition and tracing of the testing fluid.

6 Concluding remarks

As indicated in previous reports, the GRG is satisfied with the progress made, and continues to be impressed by the systematic and consistent approach adopted by the NWMO to conduct geoscientific site evaluation. The NWMO has developed sound workflows for the various field and interpretation studies to ensure consistency, which allowed the GRG to carefully assess approaches, interpretations and conclusions. The GRG has been and is actively interacting with the NWMO team to assist in a proactive manner to ensure clarity and consistency in approaches and communication of results. On this basis, the GRG supports the overall outcomes from these studies at this stage of investigation.

The GRG has made many suggestions for data interpretation process improvements and is pleased to report that the NWMO at all times is responding to all identified issues in a timely, highly transparent, technically sound and professional manner. The GRG also has started to review drilling test plans for the South Bruce site and will work with the NWMO team to ensure consistency in future work planned at this site.

Based on the experience of its members and as indicated previously, the GRG feels that the adopted approach and the quality of the studies by NWMO continue to follow or exceed international practices at this phase of site evaluation. The GRG is looking forward to seeing the first development of site-scale models in the Ignace area (Revell site), and also awaits with interest for the results of further drilling and seismic investigations at Ignace and the start of drilling in the South Bruce area.

7 References – Documents available from www.nwmo.ca

- NWMO, 2010. Moving Forward Together: Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel, Nuclear Waste Management Organization.
- APM-GRG, 2013. 2012-2013 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
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DesRoches, A., Sykes, M., Parmenter, A. & Sykes, E., 2018. Lineament Interpretation of the Revell Batholith and Surrounding Greenstone Belts. Nuclear Waste Management Organization NWMO-TR-2018-19.

8 Attachment - Brief biographies of the APM-GRG members

The APM-GRG is composed of five internationally recognized experts from Canada, Sweden, Switzerland, and Australia. They combine extensive multidisciplinary international experience in areas relevant to the siting of deep geological repositories in both crystalline rock and sedimentary rock formations.

Dr. Peter Kaiser

Dr. Peter Kaiser, Chairman of the APM-GRG, is Professor Emeritus of Mining Engineering at Laurentian University, former Chair for Rock Engineering and Ground Control, former Director of the Rio Tinto Centre for Underground Mine Construction, and former Founding Director of the Centre for Excellence in Mining Innovation. His interests lie in geomechanics, underground excavation stability, mine design, mechanized excavation, and the applications of other emerging technologies that increase mining safety and productivity. Dr. Kaiser is a Fellow of the Canadian Academy of Engineers and a Fellow of the Engineering Institute of Canada.

Dr. Sandy (Alexander) Cruden

Dr. Sandy (Alexander) Cruden is Professor of Tectonics and Geodynamics in the School of Earth, Atmosphere and Environment at Monash University (Australia). Dr. Cruden has more than 25 years of geoscience experience related to structural geology, analysis and characterization in both crystalline and sedimentary rock settings. Dr. Cruden completed a fault reactivation analysis and structural characterization of southwestern Ontario as part of site characterization activities for Ontario Power Generation's proposed Low- and Intermediate-Level Waste Deep Geologic Repository at the Bruce site.

Dr. Andreas Gautschi

Dr. Andreas Gautschi was Chief Geoscientific Advisor at the Swiss National Cooperative for the Disposal of Radioactive Waste. Since his retirement he works as an international geoscientific consultant. Dr. Gautschi has more than 30 years of geoscience experience related to the planning, coordination and implementation of site evaluation programs for deep geological repositories in both crystalline and sedimentary rocks. He coordinated successful geoscience activities that contributed to the selection of the Opalinus Clay formation as the preferred geologic setting for the long-term management of high-level waste in Switzerland. He still has a lectureship at ETH Zurich on Deep Geological Disposal of Radioactive Waste.

Dr. Michael Stephens

Dr. Michael Stephens is a retired Senior State Geologist with the Geological Survey of Sweden in Uppsala. Dr. Stephens has been actively involved in the Swedish site evaluation process, including country-wide reconnaissance studies conducted in Sweden to identify potentially suitable regions for hosting a deep geological repository, geoscientific feasibility studies, and the detailed site characterization of the Forsmark site which was selected by SKB (the Swedish Nuclear Fuel and Waste Management Company) as the site for the deep geological repository for used nuclear fuel in Sweden.

Mr. Anders Ström

Mr. Anders Ström is Senior Program Manager of final disposal solutions for spent fuel at SKB (the Swedish Nuclear Fuel and Waste Management Company). Mr. Ström has been actively involved in SKB's siting program since the early 1990s, among other things, in charge of the development of requirements on the crystalline rock for the spent fuel repository and criteria for site evaluation. During the site characterization project, he was Chief Project Manager for the multidisciplinary site descriptive modelling conducted for the two candidate sites at Forsmark and Laxemar-Simpevarp (Oskarshamn). He is now also in charge of the close co-operation between SKB and Posiva, in Finland, for implementing final disposal solutions according to the KBS-3 concept.